A Discussion on the Current MUTCD Standards on Traffic Control Signals for Freeway Entrance Ramps

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ABSTRACT

In Section 4I.02 of the newly published Manual on Uniform Traffic Control Devices (MUTCD), standards were specified for the placement of signal heads for traffic control signals at freeway entrance ramps, or ramp meters. For simultaneous operations, i.e. when ramp control signals are operated such that green signal indications are always displayed simultaneously to all of the lanes on the ramp, a minimum of two signal faces per ramp shall face entering traffic. For staggered operations, i.e. the ramp control signal are operated such that green signal indications are not always displayed simultaneously to all of the lanes on the ramp, one signal face shall be provided over the approximate center of each separately-controlled lane.

Based on a nation-wide survey, it was realized that the two standards did not fully reflect the state-of-the-practice with respect to ramp metering operations. Due to the lack of significant conflicting movements at ramp meters, for any on-ramp lane, a minimum of one overhead mounted, or one upper and one lower roadside-mounted signal face is sufficient to control the metering operations. The minimum necessary number of signal faces changes according to the total number of lanes, how the signal faces are mounted (overhead or roadside mounting), and how the meters are operated (simultaneous or staggered). Suggestions are made to revise the two standards to better reflect the current nation-wide practices, and better consider the specific operational needs for ramp meters.

Key words: Ramp Meter, Signal Head, Placement, Standard, Operations

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THE CURRENT MUTCD STANDARDS

In Section 4I.02 of the newly published Manual on Uniform Traffic Control Devices (MUTCD) [1], there are two new standards specified for traffic control signals for freeway entrance ramps, or ramp meters. These two standards are quoted here in verbatim to facilitate the following discussions.

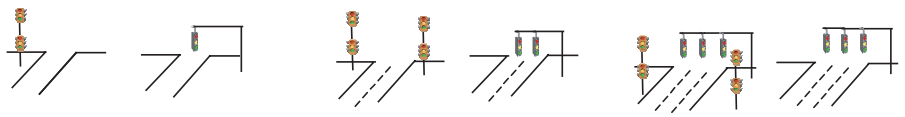
If only one lane is present on an entrance ramp or if more than one lane is present on an entrance ramp and the ramp control signals are operated such that green signal indications are always displayed simultaneously to all of the lanes on the ramp, then a minimum of two signal faces per ramp shall face entering traffic. This standard is termed for short in this paper as standard for Simultaneous Operations.

If more than one lane is present on an entrance ramp and the ramp control signal are operated such that green signal indications are not always displayed simultaneously to all of the lanes on the ramp, then one signal face shall be provided over the approximate center of each separately-controlled lane. This standard is termed for short in this paper as standards for Staggered Operations.

THE STATE-OF-THE-PRACTICE IN STATES OF CALIFORNIA, GEORGIA, MINNESOTA, NEVADA, TEXAS, UTAH, WASHINGTON, AND WISCONSIN

California has the largest inventory of traffic control signals at freeway entrance ramps, or ramp meters in this nation. By the end of 2010, the total number in operation has reached 2379 locations, with additional 1650 locations planned. In California, these signals are mostly side-mounted, with the standard located one foot downstream of the limit line on the side of on-ramp. Overhead mounting is used mostly at three-lane on-ramps, sometimes at two-lane on-ramps, and rarely at single-lane on-ramps. For example, in the San Francisco Bay Area, out of the total of 298 operational ramp meters (locations), 254 are side-mounted, and 44 are overhead mounted. For all the overhead mounted locations, 36 are at three-lane on-ramps, seven are at two-lane on-ramps, and one at single-lane on-ramps. In the Los Angeles area, out of the total of 999 existing ramp meters, only 66 are overhead mounted (27 are at freeway to freeway connectors and 29 at multilane on-ramps). The overhead mounted meters are less than 7%.

As shown in Figure 1, for single lane on-ramps, signals may be installed on either the right- or the left-hand side of the on-ramp. In California, signal standards are placed very close, say one foot downstream of the limit line [2]. There are typically two signal heads on each standard, with the lower head intended for use by the stopped motorists, and the upper one for use by the approaching motorists. For two-lane on-ramps, signals are installed on both sides of the on-ramp. For three-lane on-ramps, signals are installed overhead on mast arms, and side-mounted ones may be installed for better visibility. In California, ramp meters are typically mounted overhead for three-lane on-ramps; however, if site conditions justify, mast arms may also be used at two-lane or even one-lane on-ramps. Overhead mounted signals are typically placed at least 21 m (70 ft.) downstream of the limit line [2], so that such signal heads may serve both the approaching and stopped vehicles.



One-lane onramp Two-lane onramp Three-lane onramp

Figure 1: Signal head placement at one-, two-, and three-lane on-ramps in California

In Georgia, there are about 160 existing ramp meters, with an additional 18 planned to be implemented in the near future. It is estimated that 60% of the meters are side-mounted, and the rest overhead mounted. For overhead mounted meters, two signal heads per lane of metering are used, and therefore there are four signal heads for a two lane entrance ramp as shown in Figure 2.

In Minnesota, there are 420 ramp meters. All these ramp meter signal heads are side-mounted. Because the signal standards are placed within a few feet downstream of the limit line, there are two heads per lane installed: one upper head for approaching motorists, and one lower head for stopped motorists. One special feature of these side-mounted meter standards is that they are designed to be break-away.

Figure 2: Two overhead signal heads each lane in Georgia

Nevada Department of Transportation has 41 operational ramp meters, with 26 more currently under construction. All ramp metering (2-section) signal heads are overhead mounted directly over the lane, except for four ramps where the heads are side-mounted. Two of these four ramps are single lane ramps. Except for one location, all lanes are alternately served (staggered operation). In fact, the only exceptional location operates in staggered mode previously. But the motorists seemed to watch the opposite lane's signal indication, and were often observed to run the red in their own lane; so it

was altered to simultaneous operations (let both lanes "go" together). As of 2009, all HOV preferential lanes that previously were un-metered have also been metered.

All existing ramp meters in Texas are operated in the Greater Houston Area. There are a total of 86 meters, with no planned projects to install more ramp meters. All these metering locations involve only single-lane entrance ramps. All of these signal heads are side-mounted on a pedestal pole.

In the State of Utah, there are 52 operational ramp metering locations, of which, 46 involve multilane entrance ramps. The signal heads are mounted on mast arms for the majority of multilane ramp meters. Therefore, in Utah, most of their metering heads are overhead mounted.

In the State of Washington, there are 152 ramp metering locations, of which, 97 locations are single-lane entrance ramps, and 55 locations are multiple lane entrance ramps. It is typical that ramp meter heads are overhead mounted at on-ramps with two or more lanes; and are side-mounted at single lane on-ramps. There are only two locations where meters are side-mounted when there are two metered lanes. There is one location when mast arm is used for a single lane entrance ramp.

Wisconsin has approximately 125 existing ramp meters, with very few planned in the future. At one- or two-lane ramps, ramp meters are side-mounted; while at ramps with three- or more lanes, ramp meters are overhead mounted, supplemented with side-mounted ones on separate poles. Overhead mounted meters are estimated to be between 10~20% of all ramp metering locations.

The nation-wide survey indicated that there are more than 3400 ramp meters are in operation. In practice, ramp meters are either side-mounted or overhead mounted. For single lane ramps, side-mounted signals are typically used across the states with little difference. For on-ramps with three- or more lanes, signals are consistently overhead mounted. However, for two-lane on-ramps, ramp meters may be side- or overhead-mounted to operate successfully. For example, in the States of Nevada, Utah, and Washington, overhead mounting is used; while in California, Minnesota, and Wisconsin, roadside mounting is typical. As the Minnesota Department of Transportation responded, "After nearly 40 years of operations, we have never had a safety problem with side-mounted design. To follow the new MUTCD mandate, the total costs are estimated at about $20 million ($50,000 per location for the overhead structure and guardrail protection)."

DISCUSSIONS ON THE CURRENT MUTCD STANDARDS

Simultaneous Operations

In its current format, the description about simultaneous operations in the MUTCD is vague and incomplete, and does not offer the necessary guidance practitioners need. First of all, the minimum two signal faces per ramp specified may not be sufficient for the ramp meter to function, without clearly specifying how the two signal faces are going to be installed. Ramp meters serve two types of entering traffic, namely the approaching traffic and the stopped traffic. Side-mounted ramp meters are typically placed just one foot downstream of the limit line [2]. Such placement helps keep ramp meters out of the sights of the mainline traffic; it also provides cues for the approaching

motorists about where to stop. However, such placement makes it almost impossible for the stopped motorists to view the upper head (bottom of signal housing about 2.44~3.05 m (8~10 ft.) above ground [1]). Therefore the lower head (bottom of signal housing about 1.37~1.83 m (4.5~6 ft.) above ground [1]) must be provided for the stopped motorists. For the approaching motorists, on the other hand, the upper signal head is indispensable, because they cannot see the lower signal heads. At urban street intersections, side-mounted heads are typically placed at the far side of the cross street, offering acceptable viewing angles for the stopped motorists and no additional lower heads are needed. Therefore, in order for a side-mounted ramp meter to function at an one- and two-lane on-ramp, there must be a minimum of 2, and 4 side-mounted signal heads, respectively.

In addition, the current standards do have exceptions. A single overhead signal head satisfies the needs of both stopped and approaching motorists at a single lane on-ramp as shown in Figure 3. Indeed, the current MUTCD allows using a single overhead signal head to control the middle lane of a three-lane on-ramp [1]. The shown situation in Figure 3, a single lane on-ramp controlled by a single overhead signal head, is very similar to the middle lane of a three-lane on-ramp. Why there must be one more signal head just to satisfy the MUTCD mandate? Certainly, the shown situation in Figure 3 does have two roadside mounted signal heads, but they are good to have, and should not constitute the minimum requirement. On the other hand, a three-lane on-ramp may not properly function if controlled by the two minimum number of signal faces, even both mounted overhead, due to the possible blockage from neighboring vehicles. Clearly, the current MUTCD standards did not fully consider the specifics of ramp metering operations in practice, and need to be modified.

Figure 3: Single lane controlled by overhead-mounted signal

It is the view of the authors that a practical standard specifying the minimum number of heads per ramp has to fully consider at least the following three factors: (1) the total number of lanes at an on-ramp; (2) the needs of both approaching and stopped motorists; and (3) the way the signal heads are mounted and operated. For simultaneous operations, the current MUTCD mandate could better be revised to: *If only one lane is present on an entrance ramp or if more than one lane is present on an entrance ramp and the ramp control signals are operated such that green signal indications are always displayed simultaneously to all of the lanes on the ramp, then the minimum number of upper signal heads per ramp shall be the same as the total number of lanes at the limit line. For side-mounted signals, the same number of lower signal heads shall also be provided for viewing by stopped motorists at the limit line.*

Staggered Operations

For staggered operations, the current MUTCD standard mandates that one signal head be provided over the center of each separately controlled lane, which means that overhead structures must be used to support these signal faces. This requirement is not well supported by ramp metering practices in some states, such as California and Minnesota with more than 50 years of history of operating ramp meters. As mentioned in previous Sections of this paper, ramp meters are typically side-mounted at two-lane on-ramps in California and Minnesota.

It is true that side-mounted signals are not perfect for staggered operations. For example, at multilane on-ramps, motorists may follow the wrong indications. Indeed, field observations indicated that motorist confusions do occur across California (Fresno, San Bernardino, and Stockton). However, field observations also indicated that such confusions occurred typically at the initial turn-ons, and motorists soon learned to follow the correct indications. Even if the motorists follow the wrong indications, the consequences are not catastrophic due to the fact that there are no significant conflicting movements at ramp control signals. Across California, few official motorist complaints were received about side-mounted signals. The author could not locate any substantial study justifying that overhead signal faces are indispensable for two-lane on-ramp control. Therefore, despite the fact that side-mounted signal standards may encroach upon clear recovery zones and are subject to knock-downs by errant vehicles, side-mounted signals are very widely used across California, for both simultaneous and staggered operations. To alleviate the motorist confusion problem, field ramp metering engineers recommend changing the supplemental sign as shown in Figure 4 from "EACH LANE" to "THIS LANE" for staggered operations, although there is no conclusive research verifying the efficacy of such change.

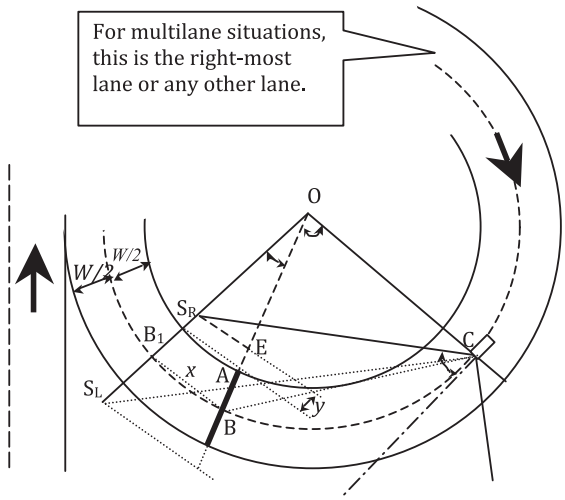
One apparent disadvantage of overhead structures is the increased construction costs for agencies. Also, overhead installation mandate allows for less design flexibility for the engineers, too. What is more, at loop on-ramps, overhead signal faces provide less available sight distance than side-mounted ones for approaching motorists. Overhead-mounted signals are typically installed about 21 m (70 ft.) downstream of limit line; while side-mounted ones are just 0.3 m (1 ft.) downstream of the limit line [2]. Due to the curvature of loop on-ramps, almost always, signals installed on the outer side of

Figure 4: Two-cars-per-green each lane sign

curve are seen first by the approaching motorists, followed by signals in the middle of lanes and the inner side of curve.

In 2007, a detailed analytical analysis was conducted to evaluate the placement design of ramp meters at loop on-ramps [3]. Two fundamental requirements of the MUTCD, i.e. driver's cone of vision and stopping sight distance were explicitly built in and considered. For a typical loop on-ramp shown in Figure 5, overhead mounted signals always call for a larger radius to satisfy the necessary stopping sight distance and motorist's cone of vision. As shown in Table 1, at single lane on-ramp, a 210 m (700 ft.) radius has to be designed when meters are installed overhead; while a 72 m (240 ft.) radius will be sufficient when meters are roadside mounted. For multilane loop on-ramps, side-mounted signals also call for smaller curve radius. Clearly, for retrofitting situations, side-mounting will adapt better to site constraints; when overhead mounting becomes necessary, motorist's stopping sight distance and cone of vision have to be carefully evaluated to ensure successful metering operations. In San Diego, California, one overhead-mounted ramp meter at a loop on-ramp had to be shut down after a few days of initial turn-on due to insufficient available sight distances. Additional advance warning devices or even side-mounted signal had to be provided to supplement the overhead signals.

On January 5, 2011, recognizing the issues with this mandate, the Federal Highway Administration (FHWA) issued a memorandum agreeing that two separately-controlled lanes can be satisfactorily controlled with two side-mounted faces (one mounted at normal height and one mounted low on the same pole) (4). The mandate is revised to:



Notes:

(1) *W*=lane width, *W*= 3.6 m (12 ft.) for single lane ramp, and *W*=7.2 m (24 ft.) for two lane onramp, *W*=11 m (36 ft.) for three lane onramp;
(2) S_R=right-hand-side signal location;
(3) S_L=left-hand-side signal location;
(4) *x*= distance from center of limit line to center of road where signal head is located;
(5) *y*= lateral distance from right edge of traveled way to the signal head: positive to the right, and negative to the left.
(6) OC=R

Figure 5: Definition of the locations of overhead- and side-mounted signal heads

If multiple lanes are present on an entrance ramp and the ramp control faces are operated such that green signal indications are not always displayed simultaneously to all of the lanes on the ramp, then [4]:

A. If there are two separately-controlled lanes, a minimum of two signal faces shall be provided for each of the two lanes, with both mounted overhead, both mounted at the side of the roadway on a single pole, or a combination thereof.

B. If there are three or more separately-controlled lanes, one signal face shall be provided over the approximate center of each separately-controlled lane.

Table 1: Comparison of overhead- and side-mounted signal heads

	Signal Location	Single Lane On-ramp	Two Lane On-ramp*	Three Lane On-ramp*
Overhead	*x, m*	21.34	21.34	21.34
Mounting	*y, m*	-1.83	-5.49	-9.14
	R, m	213.4	164.7	123.4
Right-Hand-Side	*x, m*	0.61	0.61	0.61
(Inner curve)	*y, m*	2.44	2.44	2.44
Mounting	*R, m*	187.5	187.5	187.5
Left-Hand-Side	*x, m*	0.61	0.61	0.61
(Outer curve)	*y, m*	-4.88	-8.53	-12.19
Mounting	*R, m*	73.15	30.5	15.2
Remarks	The table is developed to show that overhead mounted signals will need larger radius to satisfy the sight distance of approaching vehicles. Therefore, at loop on-ramps, side-mounted, especially left-hand-side mounted signals are very helpful.			

* Right-most lane result only.

Even in this Memo, the description for two-lane on-ramps still concentrated on the minimum number of two signal faces, and gave unnecessary flexibility on how the two signal faces should be mounted. In the Memo, the two signal faces can be mounted both overhead, both roadside, or a combination thereof. First, to place both signal heads overhead to control a single on-ramp lane, as shown in Figure 2, does not help with the ramp metering operations, if not causing confusion. Second, when the two faces are both roadside-mounted, the revised standard failed again to specify that there must be one lower signal head per lane because the lower head is a must-to-have for the stopped motorists. Finally when one face is overhead-mounted, and one roadside-mounted, the side-mounted one is in fact good to have, but unnecessary. Therefore, this revised standard need to be modified again.

To fully consider the number of lanes, the supporting structure type, and the needs of the stopped motorists, the FHWA mandate standard for staggered operations may better be modified to: *If more than one lane is present on an entrance ramp and the ramp control signals are operated such that green signal indications are not always displayed simultaneously to all of the lanes on the ramp, then one signal face shall be provided for each separately controlled lane over the approximate center of each lane if the signal face is overhead mounted. If there are only two separately-controlled lanes on a ramp, each lane can be satisfactorily controlled with one upper and one lower signal head mounted on a single pole located at the side of the lane. For overhead-mounted signals, additional side-mounted signal faces shall be provided at loop on-ramps where sight distance is deficient.*

SUMMARY

In this paper, a discussion was presented regarding the two current MUTCD standards for the number and placement of signal heads at freeway entrance ramps. The standards failed to fully consider the nation-wide ramp metering practices and the needs of both approaching and stopped motorists at the limit line. Due to the lack of significant conflicting movements at ramp meters, for any on-ramp lane, a minimum of one overhead mounted, or one upper and one lower roadside-mounted signal face will be sufficient to control the metering operations. Based on survey of the state-of-the-practice across the United States and necessary analyses, modifications are suggested for both simultaneous and staggered operations. For simultaneous operations, the standard is proposed as: *If only one lane is present on an entrance ramp or if more than one lane is present on an entrance ramp and the ramp control signals are operated such that green signal indications are always displayed simultaneously to all of the lanes on the ramp, then the minimum number of upper signal heads per ramp shall be the same as the total number of lanes at the limit line. For side-mounted signals, the same number of lower signal heads shall also be provided for viewing by stopped motorists at the limit line.*

On the other hand, the standard for staggered operations is proposed as: *If more than one lane is present on an entrance ramp and the ramp control signals are operated such that green signal indications are not always displayed simultaneously to all of the lanes on the ramp, then one signal face shall be provided for each separately controlled lane*

over the approximate center of each lane if the signal face is overhead mounted. If there are only two separately-controlled lanes on a ramp, each lane can be satisfactorily controlled with one upper and one lower signal head mounted on a single pole located at the side of the lane. For overhead-mounted signals, additional side-mounted signal faces shall be provided at loop on-ramps where sight distance is deficient.

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